RADIATION EXPERIMENTS ON THE Z-MACHINE

G. C. Idzorek, R. E. Chrien, W. Matuska, D. L. Peterson, and F. J. Swenson
Los Alamos National Laboratory+
Los Alamos, New Mexico, USA
G. A. Chandler, J. L. Porter, L. E. Ruggles
Sandia National Laboratories*
Albuquerque, New Mexico, USA

Abstract

High temperatures generated from imploding wires arrays on the Sandia National Laboratories Z-machine produce a radiation source with a bolometric temperature of several hundred eV. By surrounding the z-pinch implosion with a hohlraum a nearly Planckian source of about 140 eV peak temperature and 10 ns width is created. However the high temperature peak is preceded by a lower temperature foot of about 30 eV temperature lasting almost 100 ns. To prevent experiments from being destroyed by the pre-pulse a thin plastic burn-through foil is placed between the hohlraum and the experiment. The foil thickness and composition are chosen to ionize and become transparent at the time the high temperature pulse occurs. Also at these temperatures diagnostic holes in the hohlraum wall vaporize and material jets into the hole reducing the effective hole size. We present a series of Z-machine experiments which characterized and modified the raw radiation source into a suitable driver for radiation flow experiments.

I. THE Z-MACHINE

Sandia National Laboratories Z-machine pulsed power facility [1] consists of 36 Marx modules driving 36 pulse-forming lines which converge onto magnetically insulated transmission lines connected to a small diameter wire array. The Marx generators are charged to 90 kV and when fired dump a 5 MV pulse into the pulse forming lines. The pulse lines convert the long Marx pulses into short electrical pulses and synchronize the pulses to arrive simultaneously at the wire array target. In our experiments the target consisted of 300 ten-micron diameter tungsten wires symmetrically arranged in a 20 mm diameter cylinder 1 cm high. The converging electrical pulses reach a peak current of 20 MA in the wire array which then implodes radially due to the **J x B** forces on the wires. When the wire plasma converges on axis the kinetic energy is converted to heat producing temperatures of about 200 eV. The 11.4 MJ of stored electrical energy in the Marx modules is converted to about 2 MJ of radiation with peak radiation power in the 200 TW range.

II. X-RADIATION SOURCE

Surrounding the 20 mm wire array is a 24 mm diameter gold plated stainless steel hohlraum can that absorbs the wire array pinch radiation and then re-emits it in a nearly Planckian spectrum with a temperature around 140 eV. A two dimensional radiation magnetohydrodynamic calculation of a wire implosion implosion inside a gold hohlraum is shown in figure 1. Diagnostic holes in the can wall are viewed with arrays of well-characterized x-ray filtered silicon photodiodes (SiD) [2] and carbon cathode photoemissive X-Ray Diodes (XRD) [3].

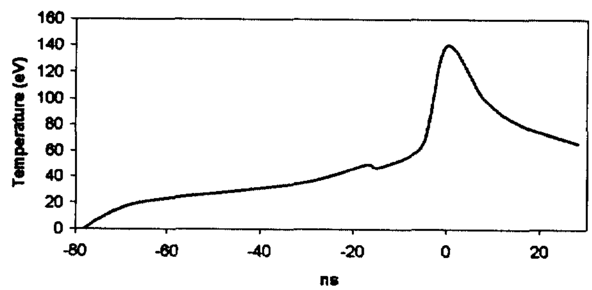

Figure 1. 2-D calculation of Z-hohlraum

By folding the calibrated detector x-ray spectral response with the source-detector geometry and calculated Planckian spectra and then integrating the result a table of Planckian source temperature versus detector signal output can be generated. Using this table the time versus detector signal data measured from a shot can be converted into time versus Planckian temperature data. This method assumes a single temperature Planckian source, a known source size, and the same source size for all measured photon energies. If any of the assumptions fail then detectors with overlapping responses will give

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inconsistent temperatures. In that case more sophisticated techniques must be used which assume only the same source size for all photon energies and unfold a spectrum by iterating a best fit spectrum to the overlapping detector responses [4]. Figure 2 shows a simple Planckian table unfold of 6 SiD's and 4 XRD's viewing a 2.4-mm diameter hole in the hohlraum wall. The hole was positioned so the detectors view the inside wall of the hohlraum and avoid seeing the z-pinch centered in the hohlraum. The SiD detectors were filtered to observe the low temperature plasma of the wires converging and the XRD's measured the high temperature radiation produced when the wires collided on axis. The XRD's can observe the peak of the radiation pulse but cannot easily see temperatures below about 40 eV whereas the SiD's can see temperatures as low as 10 eV but saturate before the peak temperature is achieved. The peak provides a timing fiducial to cross check system timing. An obvious observation of Figure 2. is that the data does not appear well correlated. The early time high temperature outliers are due to signals just above background noise levels on heavily filtered high energy channels. Late time divergence is easily explained by detector and digitizer saturation recovery but early time behavior showing similar curve shapes offset in time is more problematic since overall inter-detector timing was thought to be within ½ nanosecond. Further investigation uncovered subtle timing and detector calibration issues, which once addressed greatly improved the data quality. Examination of the raw data or unfolded spectra from the detectors does not reveal these problems as clearly as this table unfold technique.

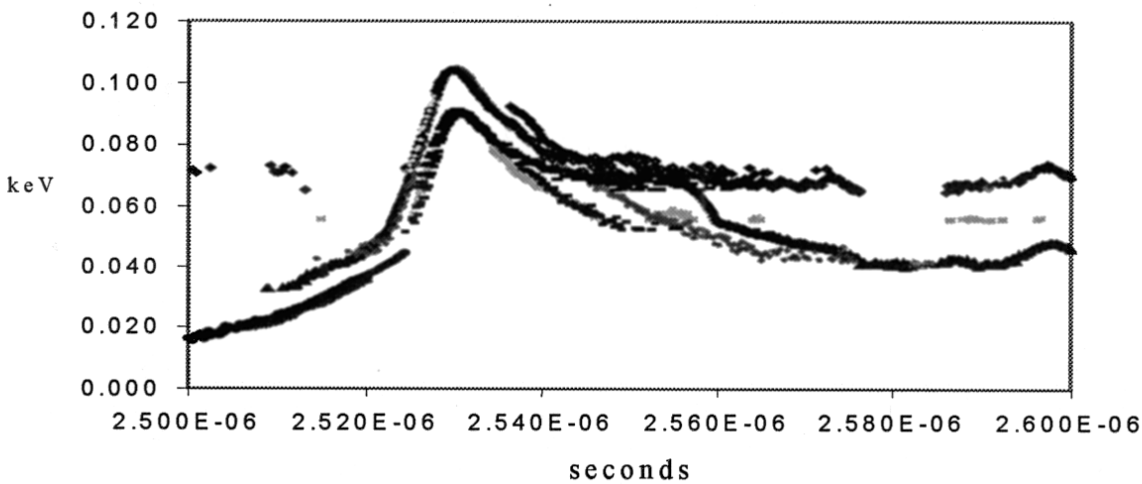

Figure 2. Planckian table unfold assumes Planckian source of known size for all detectors.

III. BURN-THROUGH FOILS

In our experiments the desired drive source is a fast rising high temperature pulse of radiation. The Z-machine low temperature pre-pulse foot will pre-heat and damage experimental packages before the desired high temperature pulse arrives. To alleviate this pre-heat damage a thin Parylene-n (C_8H_8) foil is attached inside the hohlraum covering the viewing aperture. The cold foil is opaque to the low energy photons generated by a low temperature Planckian source effectively blocking the foot radiation. As the foil absorbs energy and heats up its opacity drops as the atoms are increasingly ionized and the radiation burns through the foil. Foil thickness is selected so the burn-through time coincides with the high temperature radiation pulse. In this way the foil behaves as an extremely fast shutter blocking the foot radiation and opening to pass the high temperature pulse. In our experiments a 10-micron thick foil provided the best compromise between blocking the foot and passing the high temperature pulse. Figure 3. shows an overlay of the Z-pinch hohlraum radiation with no foil, a 5-micron foil, a 10-micron foil, and a 20-micron foil covering the viewing aperture.

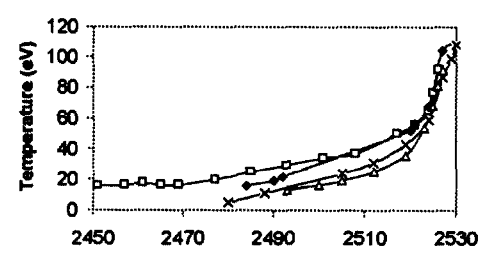

Figure 3. Burn-through foil comparison

With no foil (square symbol) covering the aperture radiation begins flowing from the hohlraum about 100 nanoseconds before the maximum temperature peak, a 5 micron foil (diamond symbol) reduces the time to about 50 nanoseconds. The 10-micron foil (X symbol) breaks out at about 40 nanoseconds before peak and the 20 micron foil (triangle symbol) burns through at about 30

nanoseconds before peak. The 10-micron foil was chosen as the best compromise between retarding the pre-pulse radiation and passing the main pulse.

IV. HOLE CLOSURE

Another difficulty encountered at high temperatures is the vaporization of material on the edges of apertures. The material streams into the viewing aperture reducing its effective area. A larger hole isn't as susceptible to closure but it will distort the Planckian nature of the hohlraum due to the large energy loss through the hole. Because the hohlraum wall is a high-Z material (gold) it will not completely ionize at these temperatures so its opacity remains high effectively blocking virtually all photons generated in the hohlraum. By coating the aperture with a Parylene-n tamping material some of the gold free streaming into the aperture is replaced by a low-Z material which can burn-through. We have performed a number of vacuum hohlraum experiments and computer simulations to study hole closure in the Z radiation environment [5]. In the experiments a multi-pinhole time gated camera was used to observe the closure of a 2.4 mm diameter gold hole tamped with 23.7 microns of Parylene-n at a number of photon energies and times. The data show that even the tamped holes close to half their original area within about 5 nanoseconds after pinch time. Lagrangian and Eulerian calculations show extreme sensitivity to the exact hole geometry and the zoning chosen. Eulerian calculations show material jets forming on the corners of the apertures whereas the Lagrangian calculation did not. This difference may have been due to zoning differences between the codes. Unfortunately the pinhole camera system lacked the resolution to observe this jetting behavior. Nevertheless good agreement between the Eulerian calculation and the macroscopic data was obtained. As more sophisticated Lagrangian-Eulerian codes become available and higher resolution imaging systems are developed the microscopic details of hole closure can be understood. However for the present experiments the macroscopic closure behavior is sufficient.

V. SUMMARY

With simple modification the Z-machine provides a fast pulsed high temperature source for radiation flow experiments. Parylene-n burn-through foils provide a simple shutter mechanism to protect experiment packages from the damaging low temperature pre-pulse radiation present in wire array implosion z-pinch machines. Hole closure, while not completely understood can be modeled to match experimentally measured macroscopic behavior. In addition the relatively large 20 mm diameter Z-machine vacuum hohlraum allows multiple experiments to be fielded simultaneously all driven by an identical source thereby eliminating the often difficult corrections to results obtained from multiple shots with a single experiment.

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